Machine Situation Awareness (MSA)

Michael McNinch
MMcNinch@cdc.gov
General Engineer
Spokane Mining Research Division

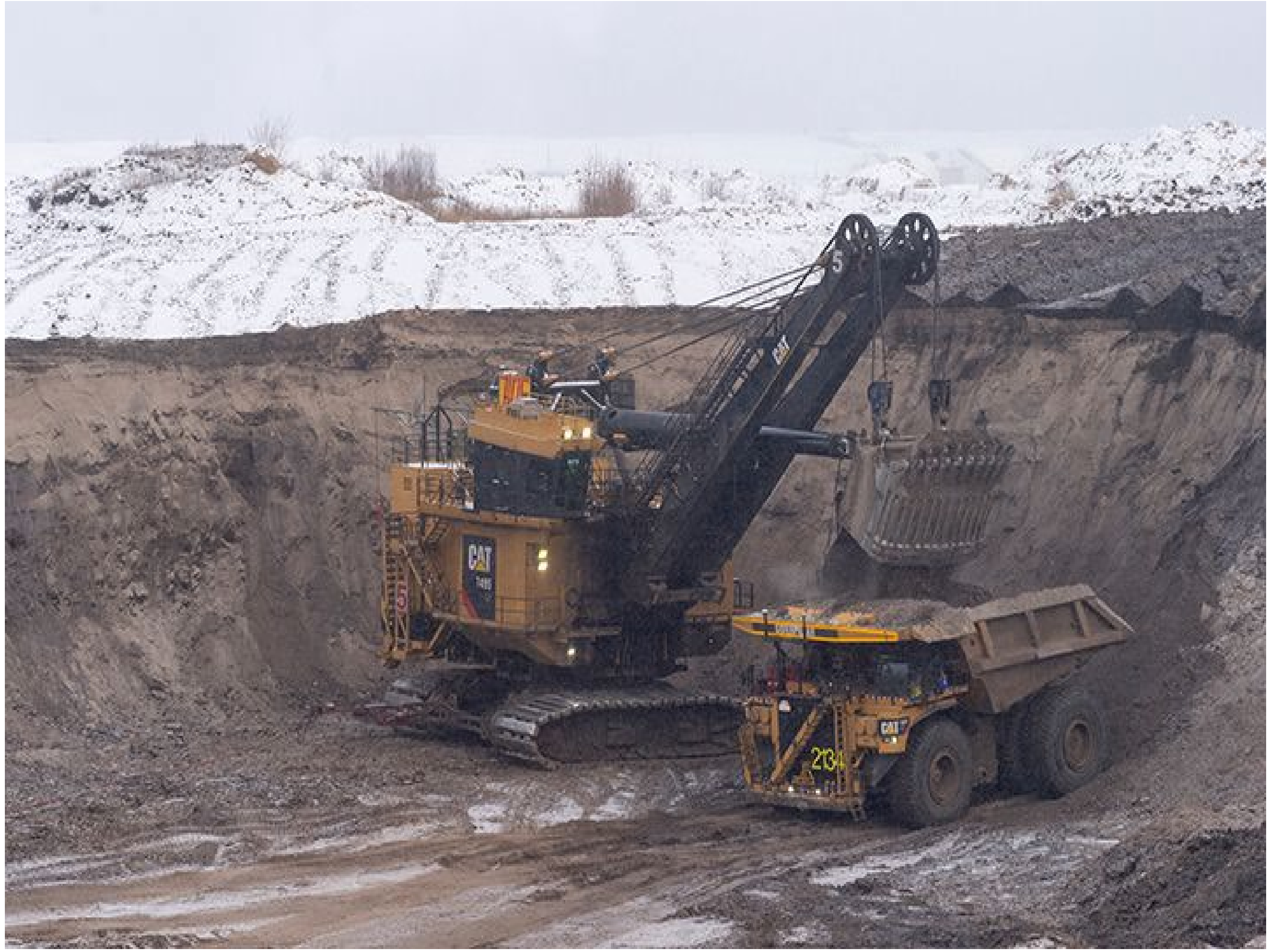


Image from Caterpillar

Current State of Autonomous Equipment

Current estimates show more than 2000 active, autonomous haul trucks worldwide.

- This has grown rapidly in recent years outside the US
- Globally, this is about 3.5% of active haul trucks

Significant expansion in types of equipment becoming autonomous:

- Light vehicles
- Water trucks
- Dozers
- Drills
- Etc.

Cat 777G Autonomous Water Truck

Current State of Autonomous Equipment

BHP's Jimblebar Mine:

- Years of autonomous haulage has resulted in a significant reduction in collision risk, increased productivity, and extended tire life.
- The reduction in incidents reported by a NIOSH/Queensland study was over 90%, from 590 incidents/million hours to 51

Based on Jimblebar and other case studies, automation can greatly improve safety while reducing costs.

Jimblebar Mine: picture from BHP

Barriers to Adoption in the US

Regulatory

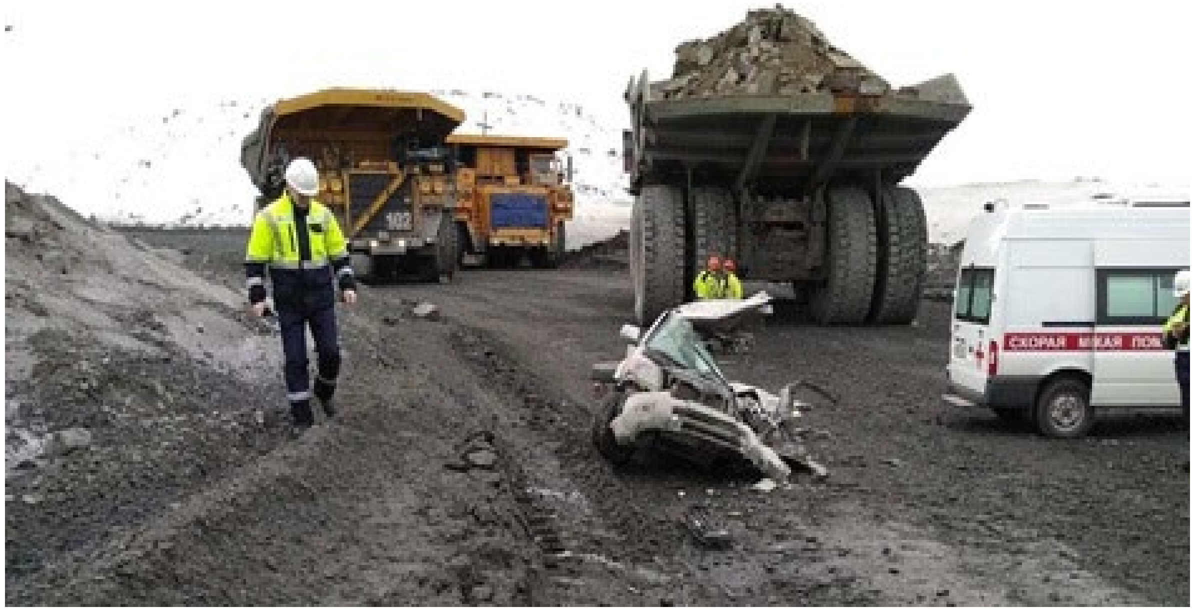
- Lack of clear rulings
- Liability

Economic

- Time required for ROI
- Smaller operations

Standardized Approach

- Springer has likened the present state of the mining sector to a collection of "automation islands“
- Represents the absence of standards, varying degrees of autonomy in equipment, and a lack of integration within the industry



Passenger car ran over by a haul truck

Definition of MSA

Situation Awareness: the ability to perceive and understand your environment, as well as predict its future state and how that will impact the task-at-hand.

Machine Situation Awareness: the above definition applied to a machine, in particular autonomous equipment, with the primary goal of ensuring peoples' safety.

Equipment Aspect of Machine Situation Awareness

- Historically we've relied on human perception and situation awareness for safe operation of equipment.

- There are some unique risks posed by the absence of human operators: limited visibility, the risk of unexpected machine behavior (loss-of-traction), and potentially inadequate communication between equipment and personnel.

We introduced the term "Machine Situation Awareness" to help bridge this gap.

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Project Goals

1. Promote safety of autonomous equipment
    - Determine sensor/equipment agnostic performance metrics for safe operation
    - Research candidate methods (vision, path prediction, hazard assessment) that satisfy established performance metrics
    - Evaluate means of reducing costs and expanding adoption in the US
    - Investigate emerging technologies

2. Act as neutral party to align development of autonomous mining technology
    - Encourage interoperability-mixed fleets, differing sensors/controllers
    - Incorporate emerging guidelines and standards (ISO, GMG)

Why are we doing this?

- Enhance mining safety through automation/autonomy
- Encourage adoption by smaller operators in the US
- Create a common baseline for successful autonomy

Advantages/Challenges in Mining Autonomy

Advantages

- Space is amenable to maintaining high-definition maps
- Small number of possible objects on-site (we know the equipment)
- Low speeds relative to automotive applications
- Some tasks are highly repetitive

Challenges

- Dirty environment: dust will reduce visibility and limit lidar, mud results in loss-of-traction
- Data is siloed

Our Approach

Design a **framework** that provides metrics and methods for:

Perception-

- What objects, people are around me?

Projection-

- What will my surroundings look like in the near future?

Hazard Assessment/Intervention-

- Is my current action safe?
- If not, what is the best course of action?

Framework Deliverables

- Object Classes and Properties for surface mines
- Minimum time horizon
- Simulation assets (where possible)

Perception

- Metrics: Acceptable Recall, Precision, mAP, etc.
- Retrainable models: code and weights
- Recommended types of sensors and general guidelines (resolution, data rate)

Path Prediction

- Code for methods (curve fitting, MPC)
- Equations used for vehicle dynamics
- Transformer model for pathing

Risk Assessment

- Cost Values for equipment
- Equations for calculating and scaling incident values
- Code/math for reachability and path finding

Candidate Methods

Perception
Object Detection and Tracking

- Extension of 4D-Net: combines features across sensors to create a pseudoimage compatible with a single shot detector. Adds time as a fourth channel across multiple frames-results in ghosting effect across trajectory to improve detection.
- Graph-based approach: supports irregular data structures (2D,3D), message sharing in graph explores spatial relationships in dense scenes (could also be used to establish context).
- Tracking can be incorporated with the model (like deepSORT) or achieved through a separate tracker: Global Nearest Neighbor (GNN), Multi-Hypothesis Tracking (MHT), etc.

Path Prediction
Path prediction and probability of interaction

- Probabilistic curve fitting: apply forward dynamics using tracked state vectors and assumptions regarding rules of the road. Variance is increased when an agent deviates from anticipated behavior. Overlap in vehicle probability distributions determines likelihood of incident.
- Model Predictive Control (MPC): control method that predicts future system state and optimizes the response using constraints. Can be applied to multiple agents, designing the model is challenging.

Hazard Assessment
Assessing Risk and Determining Safest approach

- Hazard Assessment: Hazard scoring for interactions is the product of the likelihood of an event and a predefined cost. This value can be scaled based on angle of collision, velocity, etc. This can be approached as an optimization problem within MPC or separately with a curve fitting approach.
- Reachability: compute reachable points (Hamilton Jacobi) restricted by vehicle dynamics and time horizon, determine optimal path that minimizes hazard scoring.

How will we get there?

- Research solutions in other industries (automotive, manufacturing) that can be adapted to mining
- Initial testing of algorithms on public data
- Collect training/operations data from mine sites
- Simulation testing
- Develop 1/14th scale mine for proof-of-concept testing
- Monitor guidelines and standards development, update approach as needed

Coordinate with industry to get practical feedback

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Questions?

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